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(54) **UNIVERSAL SINK/SOURCE I/O MODULE FOR INDUSTRIAL CONTROLLER**

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H03K 19/094 (2006.01)

(52) **U.S. Cl.** **326/83**; 307/115; 307/143; 700/275; 710/36

(58) **Field of Classification Search** 326/82–83; 307/115, 139, 143; 700/275, 286, 295, 297; 710/36, 38
See application file for complete search history.

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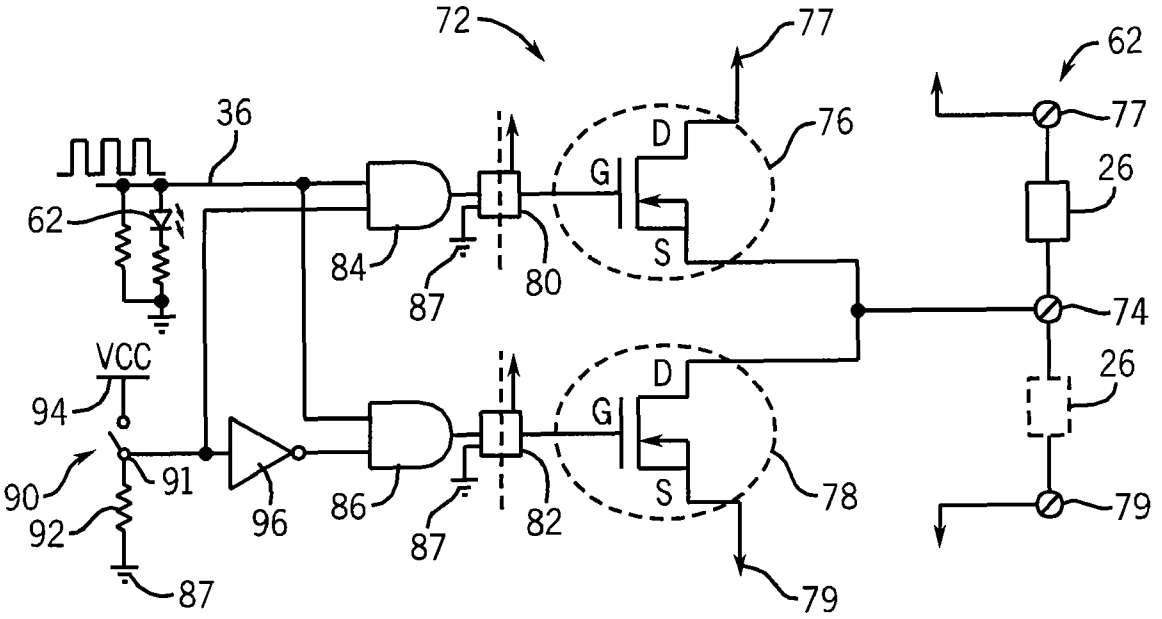
(57) **ABSTRACT**

An I/O module for an industrial controller provides single terminal outputs that may either sink or source current. This capability is provided through the use of dedicated sourcing and sinking transistors connected to the terminal and controlled by lockout logic ensuring activation of only the appropriate transistor in the correct phasing for sinking or sourcing operation modes.

19 Claims, 3 Drawing Sheets



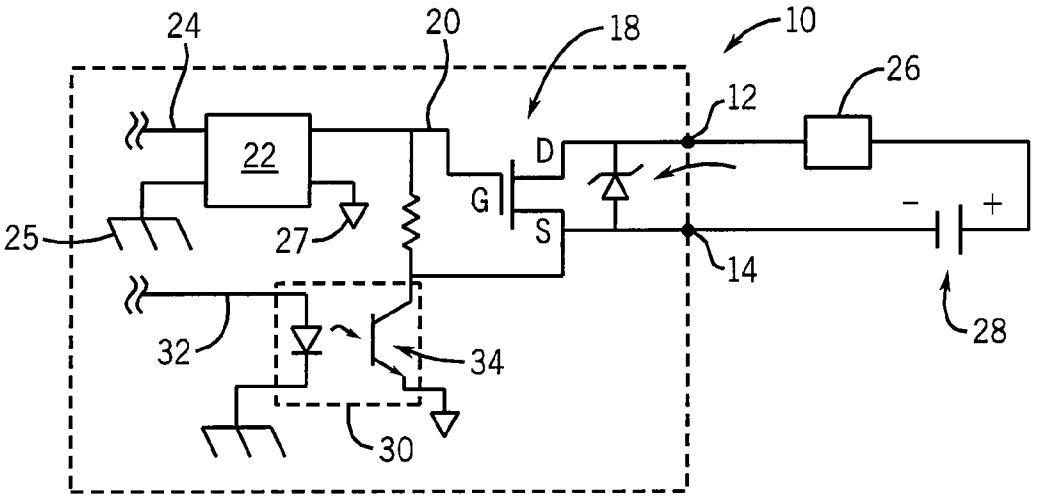


FIG. 1
PRIOR ART

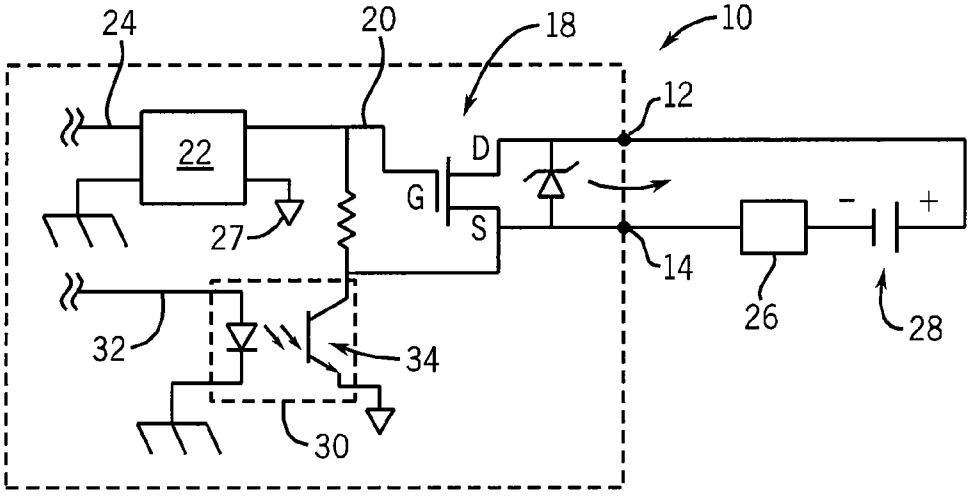


FIG. 2
PRIOR ART

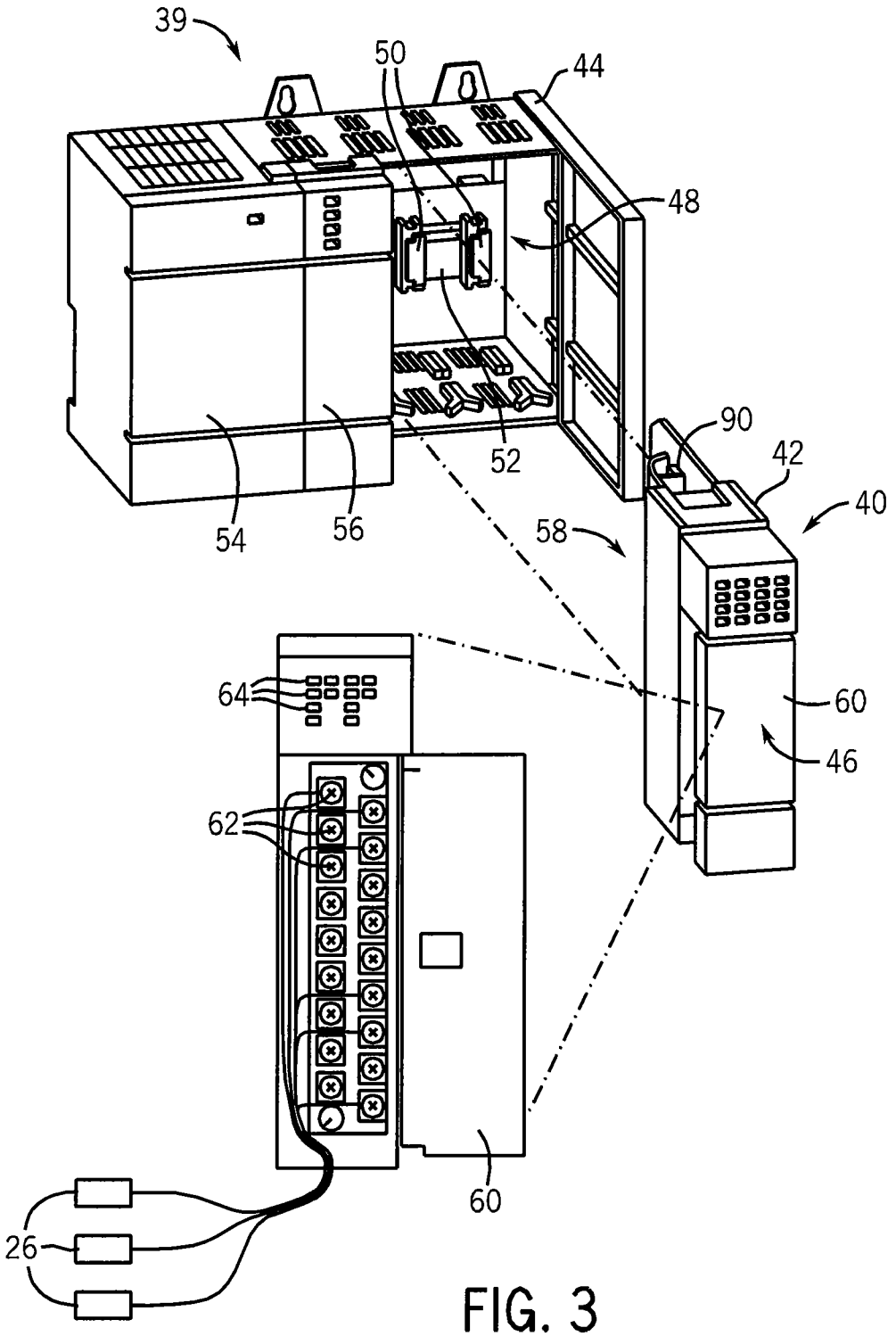


FIG. 3

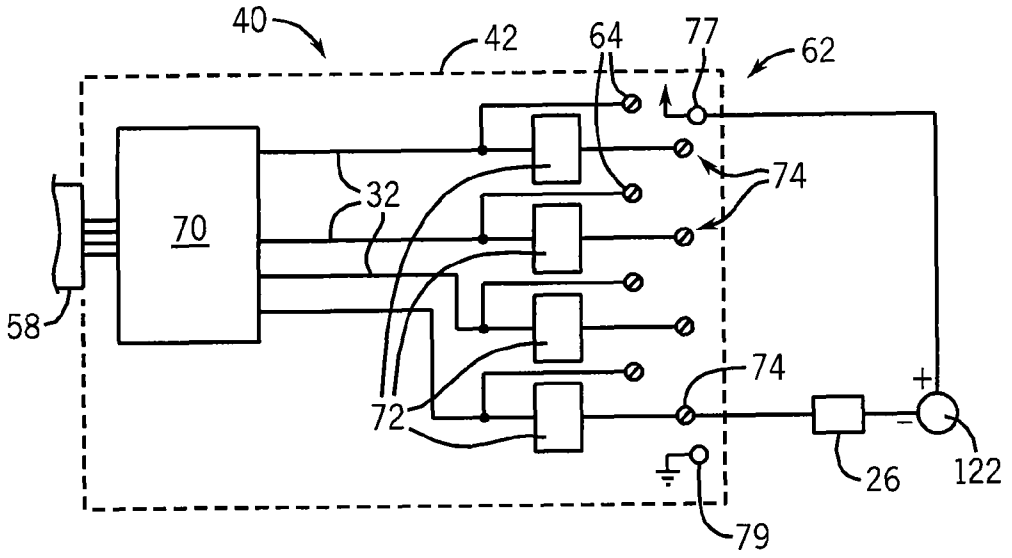

40
42
64
77
62
74
32
70
58
74
72
+
26
122
79

FIG. 4

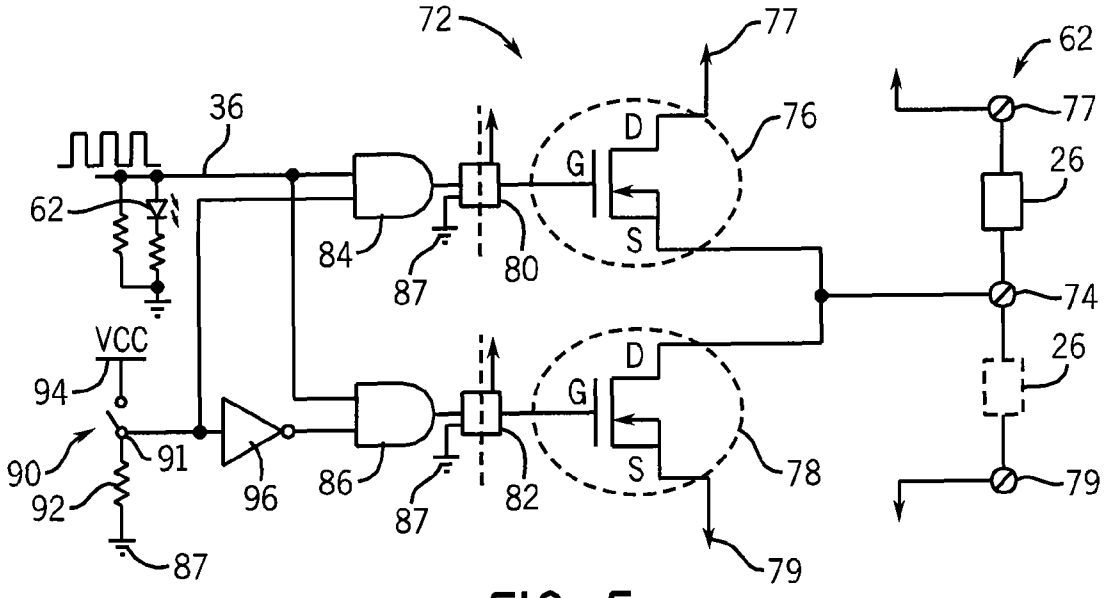

72
77
62
36
D
76
77
G
26
62
84
87
80
S
74
VCC
26
94
D
G
90
91
96
86
87
82
S
78
92
79
87
79

FIG. 5

UNIVERSAL SINK/SOURCE I/O MODULE FOR INDUSTRIAL CONTROLLER

BACKGROUND OF THE INVENTION

The present invention relates to industrial controllers used in controlling industrial machines and processes and, more particularly, to I/O modules being part of the industrial controller and providing an electrical interface between the industrial controller and the machine or process.

Industrial controllers are employed in industrial and commercial applications to control the operation of machines and processes. Generally the industrial controller executes a stored control program to control outputs to actuators on the machine or process according to inputs received from sensors on the machine or process.

Industrial controllers differ from conventional computers in providing real-time control subject to predetermined maximum delays. In addition, industrial controllers are normally constructed in a highly modular fashion to permit their hardware to be customized according to different control applications. In this latter regard, inputs and outputs to or from the industrial controller are normally handled by input/output (I/O) modules that may be attached to the industrial controller in different combinations to provide for the necessary electrical interface to the controlled machinery.

Different types of I/O modules may be used for different control applications. Input I/O modules provide specialized input circuits to receive signals from sensors and the like, and output I/O modules provide specialized output circuits to provide signals to actuators or the like. Two common output circuits are alternating current (AC) output circuits, typically employing an SCR or thyristor to switch an AC signal, and direct current (DC) output circuits typically employing a transistor to switch a DC signal. DC output circuits are often distinguished according to whether they provide "sinking outputs" that is, a switchable connection to ground that may receive current or "sourcing outputs" that provide a switchable connection to a power source that may output current.

In certain control applications, it may be desirable to provide both sinking and sourcing DC output circuits in a single I/O module. One method of accomplishing this, to be discussed further below, provides a single "floating" transistor that may be alternately connected to a load (e.g. an actuator) to provide a source of current or with a different connection, a sink of current.

Referring now to FIG. **1**, a prior art universal output circuit **10** provides a first terminal **12** and a second terminal **14** connected across a drain and source terminal (respectively) of a field effect transistor (FET) **18**.

The gate of the FET **18** is connected to a floating gate drive circuit providing a constant voltage **20** with respect to an isolated system ground **27** as received from a power supply **22**. The output of the power supply **22** is floating with respect to an input system power source **24** and a system ground **25**.

When the prior art universal output circuit **10** is operating in a sinking mode, an actuator **26** will have one terminal connected to terminal **12** and the other terminal connected to a positive terminal of an externally provided DC power source **28**. The negative terminal of the externally provided DC power source **28** is connected to terminal **14**. Activation of an optical isolator **30** by digital control signal **32** causes conduction of transistor **34** of the optical isolator **30** pulling down the source terminal of the FET **18** with respect to the gate terminal at voltage **20** to bias the FET **18** into conduction drawing current into terminal **12**.

Referring now to FIG. **2**, when the prior art universal output circuit **10** is operating in a sourcing mode, the actuator **26** must be disconnected from terminal **12** and connected to terminal **14**. The remaining terminal of the actuator **26** is then reconnected to the negative power supply terminal of power source **28** while the positive power supply terminal of power source **28** is connected to terminal **12**.

In this mode, activation of the optical isolator **30** by digital control signal **32** again pulls down the source terminal of the FET **18** with respect to the gate terminal, but this time to cause a sourcing of current through terminal **14**. This dual mode of operation requires power supply **20** to be floating with respect to the power source **28**. In addition, changing the mode of operation requires a rewiring of the actuator **26** with respect to the terminals **12** and **14** and the power source **28**. This latter reconnection of terminals either requires changing the connections to the terminals of the I/O module or the use of an internal, high current capacity, multi-pole switch connected between the FET **18** and the terminals **12** and **14**.

While this approach provides great flexibility in using outputs of the I/O module, the need to change connections to the single transistor requires undesirable switching circuitry or confusing change in external wiring procedures of actuators to the I/O module terminals. The control of a floating transistor requires a floating power supply that may be susceptible to damage.

SUMMARY OF THE INVENTION

The present invention provides an I/O module DC output circuit that may either sink or source current through a given single terminal of the I/O module as determined by a single low current direction signal. This former feature simplifies wiring actuators to the I/O module and the latter feature eliminates the need for rerouting of high current signals through a switch mechanism. The complexity of creating a drive signal for a floating transistor using a floating power supply is also eliminated.

These features are provided by using a dedicated sinking and sourcing transistor permanently connected to a single output terminal but driven by lockout circuitry allowing only one transistor to operate at a time.

Specifically, the present invention provides an I/O module for an industrial controller, the I/O module providing digital control signals for controlling application of electrical power to actuators on a controlled machine during a true state of the digital control signals. The I/O module includes an electrical connector for releasably attaching the I/O module to the industrial controller for communication of the digital control signals therebetween. For a given digital control signal, the I/O module provides:

(1) a releasable terminal providing a connection to the actuator for the provision of electrical power to the actuator in accordance with the state of the given digital control signal;

(2) a first transistor device connected between the releasable terminal and a terminal receiving a first DC voltage to provide a current flow from the first DC voltage to the releasable terminal when the first transistor device is turned on;

(3) a second transistor device connected between the releasable terminal and a terminal receiving a second DC voltage to provide a current flow from the releasable terminal to the second DC voltage source when the second transistor is turned on; and

(4) a logic circuit providing transistor control signals to the first and second transistor and receiving the given digital

control signal and a direction signal indicating whether the releasable terminal should operate as a sourcing DC output or a sinking DC input.

The logic circuit operates so that when the direction signal indicates that the releasable terminal should operate as a sourcing DC output:

(i) a transistor control signal is provided to the first transistor turning the first transistor on only when the given digital control signal is true and otherwise turning the first transistor off, and

(ii) a transistor control signal is provided to the second transistor turning the second transistor off both when the given digital control signal is true and otherwise.

On the other hand, the logic circuit operates so that when the direction signal indicates that the releasable terminal should operate as a sinking DC output:

(i) a transistor control signal is provided to the second transistor turning the second transistor on only when the given digital control signal is true and otherwise turning the second transistor off, and

(ii) a transistor control signal is provided to the first transistor turning the first transistor off both when the given digital control signal is true and otherwise.

It is thus a feature of at least one embodiment of the invention to provide a universal DC output circuit that may either sink or source current depending on a simple setting received by a logic circuit.

The first and second transistors are both n-channel MOSFET transistors.

It is thus a feature of a least one embodiment of the invention to eliminate the need for p-channel MOSFETs that in the absence of drive signals will conduct possibly creating an undesirable control state.

The I/O module may further include an electrical switch manually operable to provide the direction signal.

It is thus a feature of at least one embodiment of the invention to provide a simple signal to control the mode of operation of the output signal eliminating the need to switch high current output signals.

The I/O module may include a housing fitting within a chassis. When the I/O module is in the chassis mating electrical connectors engage between the chassis and I/O module communicating the digital control signals to the I/O module. An exposed face of the housing holds the releasable terminals and the electrical switch is positioned to be covered by the chassis when the housing is fit within the chassis.

It is thus a feature of a least one embodiment of the invention to provide a user controllable mode of operation for the I/O output circuits that is resistant to inadvertent alteration after wiring is complete.

The electrical switch may provide a switchable connection to a first electrical voltage and a resistive connection to a second electrical voltage so that when the switchable connection is open the direction signal indicates that the releasable terminal should operate as a sinking DC output.

It is thus a feature of a least one embodiment of the invention to provide a switch that fails in the sinking mode reducing the possibility of an undesired control state.

The I/O module may further include a releasable terminal receiving the first DC voltage.

It is thus a feature of a least one embodiment of the invention to permit the use of user supplied voltage sources for driving actuators.

The I/O module may further include a first and second optical isolator receiving at an isolated input the transistor control signals for the first and second transistors and receiving at an isolated output the first DC voltage for generation of the isolated transistor control signals.

It is thus a feature of a least one embodiment of the invention to provide electrical isolation between the actuator signals and the signals of the industrial controller.

The I/O module may include a third releasable terminal receiving the second DC voltage.

It is thus a feature of a least one embodiment of the invention to permit a ground terminal that does not change depending on the operation of the device as sinking or sourcing.

The I/O module may include an illuminated indicator associated with the releasable terminal illuminating when the digital control signal is logically true to provide a visual indication of when the digital control signal is logically true.

It is thus a feature of a least one embodiment of the invention to provide a consistent and familiar visual indication of the logical state of the output signal regardless of whether it is sinking or sourcing.

The I/O module may further include a serial communication circuit exchanging serial data with the industrial controller to provide the digital control signals.

It is thus a feature of a least one embodiment of the invention to provide a circuit suitable for use with modern industrial controllers using serial communication data.

These particular features and advantages may apply to only some embodiments falling within the claims and thus do not define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a prior art I/O circuit for providing both sinking and sourcing using a floating transistor and floating drive with the prior art circuit configured in a sinking mode with a first connection between the load and the floating transistor;

FIG. **2** is a figure similar to that of FIG. **1** with the I/O circuit configured in sourcing mode with a second connection between the load and the floating transistor;

FIG. **3** is a perspective exploded view of an industrial controller having interchangeable I/O modules;

FIG. **4** is a block diagram of a simplified single I/O module of FIG. **3** providing multiple DC universal outputs circuits per the present invention; and

FIG. **5** is a schematic diagram of a single universal output circuit of FIG. **4** per the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **3**, the present invention provides an I/O module **40** for an industrial controller **39**. The I/O module **40** is depicted in a first embodiment implementing "chassis I/O" where the I/O module **40** has a housing **42** that may be slidably received within a chassis **44** along with other I/O modules (not shown) and other modules including a power supply **54** and a programmable logic controller **56**.

Alternatively, the I/O module may also be implemented as "distributed I/O" and the differences in this implementation will be described below.

In the chassis I/O implementation, the chassis **44** may have a backplane **48** providing a set of releasable electrical connectors **50** interconnected by a backplane bus **52** extending along a rear wall of the chassis **44**. A corresponding connector **58** on the rear of the housing **42** of the module **40** mates with the corresponding connectors **50** when the module **40** is placed within the chassis **44** providing electrical connection, for example, between the programmable logic controller **56** and the circuitry of the module **40**. The bus **52** is typically a

high-speed serial bus providing efficient multi-bit communication. The other modules of the power supply **54** and programmable logic controller **56** may have similar connectors **50** and **58** for this purpose.

The I/O module **40** may provide access to electrical switch **90** through an opening in the housing **42** when the I/O module **40** is not fully received within the chassis **44**. When the I/O module **40** is fully received within the chassis **44**, only a front faceplate **46** of the module **40** is exposed, and the remaining portions of the housing **42** as well as the switch **90** are enclosed within the chassis **44**. In a distributed I/O implementation, the switch may remain accessible through an opening in the housing.

The front faceplate **46** of the I/O module **40** may open by means of a swinging door **60** to reveal a set of screw terminals **62** to which wires may be connected to connect internal I/O circuits of the I/O module **40** to various actuators **26**. Indicator lights **64** corresponding to each of the different output circuits and hence to particular output terminal **62** are positioned to be visible through a bezel on the front faceplate **46**.

In a distributed I/O implementation, multiple connectors **58** may provide for an Ethernet connection, an auxiliary power supply connection, input connection, and expansion board connection and the like. The housing **42** may provide for mountings to a DIN rail or the like.

Referring now to FIG. **4**, the connector **58** on the rear of the housing **42** of the I/O module **40** may connect to a decoder circuit **70** which receives digital control signals encoded in serial fashion from the programmable logic controller **56** to provide a set of separate digital control signals **32** each having a logically true or logically false state. Typically, and in this described embodiment, the logically true state is a positive voltage and the logically false is a nominally zero voltage.

The lights **64** are connected to the digital signals **32** by appropriate amplification circuitry to provide a visual indication to the user of the industrial controller **39** of the state of the particular signal **32**. In addition, the digital signals **32** are each provided to an output circuit **72** providing a universal (i.e. sinking or sourcing) output signal through given terminals **62**. In a preferred embodiment, each output circuit **72** provides an output terminal **74** to which an actuator **26** may be attached. To reduce terminal numbers, a single external power terminal **77** for receiving a positive voltage from an externally supplied voltage source **22** and a single external ground terminal **79** for receiving a ground voltage from the externally supplied voltage source **22** are shared among the output terminal **74**.

As depicted, a single load **26** may be configured in sinking mode connected to a power supply **122** having its positive terminal connected to power terminal **77**. Alternatively, not depicted, the single load **26** may be configured in a sourcing mode connected to power supply **122** having its negative terminal connected to ground terminal **79**.

While only four output circuits **72** are shown, a typical I/O module may provide 10 channel output and thus have ten outputs circuits **72** and employ only 12 total terminals.

Referring now to FIG. **5**, output terminal **74** is connected to a junction between the source of a first n-channel MOSFET **76** and the drain of a second n-channel MOSFET **78**. The drain of the first MOSFET **76** may be attached to the positive voltage obtained from terminal **77** while the source of MOSFET **78** may be attached to a ground obtained from terminal **79**.

The gate of MOSFET **76** is attached to an output of optical isolator **80** providing internally a phototransistor (not shown) sourcing power from terminal **77** so as to provide a voltage compatible with particular connection as will be described. Similarly the gate of MOSFET **78** is connected to the output of an optical isolator **82** also receiving power from terminal **77** to source this power to the gate of MOSFET **78** under the control of an internal phototransistor.

The inputs of optical isolator **80** and **82** are attached to cathodes of light emitting diodes (not shown) to receive the outputs of the AND gates **84** and **86** respectively. The anode of the light emitting diodes is connected to nonisolated ground **87**.

One input of each AND gate **84** and **86** is attached to the digital signal **36** associated with a particular output circuit **72** and driving light **64**. The remaining input of AND gate **84** connects to one terminal **91** of a mechanical switch **90**. This terminal **91** is also connected to a resistance **92** to ground **87**. The other terminal of the switch connects to a nonisolated power source **94** so that the power source **94** is switchably connected to terminal **91**.

It will be understood that damage to the switch **90** such as prevents good electrical flow (including possible contact corrosion) will therefore result in terminal **91** being pulled to ground through resistance **92**.

Terminal **91** connects through an inverter **96** to the remaining input of AND gate **86**.

The position of the switch **90** provides a direction signal at terminal **91**. When this direction signal is high, the output circuit **72** operates in a sourcing mode and when this direction signal is low, the output circuit **72** operates in a sinking mode as will be described. Specifically, when the switch **90** is closed, the output of AND gate **86** will always be low causing MOSFET **78** to be turned off (nonconducting) while the output of AND gate **84** will follow digital signal **36** causing MOSFET **76** to turn on when digital signal **36** is in a true state (high) and off when digital signal **36** is in a false state (low). This will provide a sourcing of current out of terminal **74** to actuator **26** connected between terminals **74** and **79**.

Conversely when switch **90** is opened, terminal **91** will be low causing the output of inverter **96** to go high and of the output of AND gate **86** to follow the digital signal **36** turning MOSFET **78** on when digital signal **36** is in a true state and off when digital signal **36** is in the false state. In this mode, AND gate **84** will always have a low output turning MOSFET **76** off (nonconducting). Accordingly, in this state, current is sinked into terminal **74** when digital signal **36** is in a high state to provide a sinking of current through actuator **26** connected between terminals **77** and **74**.

In this way, a single terminal **74** may source or sink current from actuators **26** or other loads without the need for a mechanical switch controlling high current flow. In an alternative embodiment, the signal at terminal **91** may be provided from the decoder circuit **70** permitting software selection (for example, using the control program on the programmable logic controller **56**) of the state of each output terminal **74**.

It will be further understood that failure of switch **90** will cause terminal **91** to go to a low state, putting output circuit **72** into the sinking mode which will generally be a safer mode when the particular wiring of the actuator **26** between terminals **77** and **74** or **74** and **79** is unknown. In one embodiment, the signal at terminal **91** produced by the switch **90** may generated by the industrial controller so that the configuration of the I/O module terminals as sinking or sourcing mode may be controlled through software.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims and may include other examples that occur to those skilled in the art. Such other examples are

intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from liberal language of the claims. Generally, as will be recognized by those of ordinary skill in the art, the features of the present invention may be implemented in different combinations of hardware and software executing on an electronic computer including just one or the other.

We claim:

1. An I/O module for an industrial controller providing digital control signals for controlling application of electrical power to actuators on a controlled machine during a true state of the digital control signals, the I/O module comprising:

an electrical connector for releasably attaching the I/O module to the industrial controller for communication of the digital control signals therebetween; and

for a given digital control signal,

(1) a releasable terminal providing a connection to the actuator for a provision of electrical power to the actuator in accordance with the state of the given digital control signal;

(2) a first transistor device connected between the releasable terminal and a terminal receiving a first DC voltage to provide a current flow from the first DC voltage to the releasable terminal when the first transistor device is turned on;

(3) a second transistor device connected between the releasable terminal and a terminal receiving a second DC voltage to provide a current flow from the releasable terminal to the second DC voltage source when the second transistor is turned on;

(4) a logic circuit providing transistor control signals to the first and second transistor and receiving the given digital control signal and a direction signal indicating whether the releasable terminal should operate as a sourcing DC output or a sinking DC input and

(a) when the direction signal indicates that the releasable terminal should operate as a sourcing DC output, providing:

(i) a transistor control signal to the first transistor turning the first transistor on only when the given digital control signal is true and otherwise turning the first transistor off,

(ii) a transistor control signal to the second transistor turning the second transistor off both when the given digital control signal is true and otherwise; and

(b) when the direction signal indicates that the releasable terminal should operate as a sinking DC output, providing:

(i) a transistor control signal to the second transistor turning the second transistor on only when the given digital control signal is true and otherwise turning the second transistor off,

(ii) a transistor control signal to the first transistor turning the first transistor off both when the given digital control signal is true and otherwise.

2. The I/O module of claim **1** wherein the first and second transistors are both n-channel MOSFET transistors.

3. The I/O module of claim **1** wherein further including an electrical switch manually operable to provide the direction signal.

4. The I/O module of claim **3** wherein the I/O module includes a housing fitting within a chassis to engage mating of electrical connectors communicating the digital control signals to the I/O module, and wherein the exposed face of the housing holds the releasable terminals and wherein the electrical switch is positioned to be covered by the chassis when the housing is fit within the chassis.

5. The I/O module of claim **3** wherein the electrical switch provides a switchable connection to a first electrical voltage and a resistive connection to a second electrical voltage so that when the switchable connection is open the direction signal indicates that the releasable terminal should operate as a sinking DC output.

6. The I/O module of claim **1** further including a releasable terminal receiving the first DC voltage.

7. The I/O module of claim **6** wherein further including a first and second optical isolator receiving at an isolated input the transistor control signals for the first and second transistors and receiving at an isolated output the first DC voltage for generation of the isolated transistor control signals.

8. The I/O module of claim **1** wherein for the digital control signal further including a third releasable terminal receiving the second DC voltage.

9. The I/O module of claim **1** further including an illuminated indicator associated with the releasable terminal illuminating when the digital control signal is logically true to provide a visual indication of when the digital control signal is logically true.

10. The I/O module of claim **1** further including a serial communication circuit exchanging serial data with the industrial controller to provide the digital control signals.

11. The I/O module of claim **1** wherein further including an industrial controller executing a stored program to read signals from input I/O modules connected to the controlled equipment to provide the state of the digital control signals.

12. A method of operating an I/O module for an industrial controller providing digital control signals for controlling application of electrical power to actuators on a controlled machine during a true state of the digital control signals, the I/O module being of a type comprising:

an electrical connector for releasably attaching the I/O module to the industrial controller for communication of the digital control signals therebetween; and having for a given digital control signal:

(1) a releasable terminal providing a connection to the actuator for a provision of electrical power to the actuator in accordance with the state of the given digital control signal;

(2) a first transistor device connected between the releasable terminal and a terminal receiving a first DC voltage to provide a current flow from the first DC voltage to the releasable terminal when the first transistor device is turned on;

(3) a second transistor device connected between the releasable terminal and a terminal receiving a second DC voltage to provide a current flow from the releasable terminal to the second DC voltage source when the second transistor is turned on;

(4) a logic circuit providing transistor control signals to the first and second transistor and receiving the given digital control signal and a direction signal indicating whether the releasable terminal should operate as a sourcing DC output or a sinking DC input; the method including the steps of:

(a) when the direction signal indicates that the releasable terminal should operate as a sourcing DC output, providing:

(i) a transistor control signal to the first transistor turning the first transistor on only when the given digital control signal is true and otherwise turning the first transistor off,

(ii) a transistor control signal to the second transistor turning the second transistor off both when the given digital control signal is true and otherwise; and

(b) when the direction signal indicates that the releasable terminal should operate as a sinking DC output, providing:

(i) a transistor control signal to the second transistor turning the second transistor on only when the given digital control signal is true and otherwise turning the second transistor off,

(ii) a transistor control signal to the first transistor turning the first transistor off both when the given digital control signal is true and otherwise.

13. The method of claim **12** wherein the first and second transistors are both n-channel MOSFET transistors.

14. The method of claim **12** wherein further wherein the direction signal is provided by a manually operable switch.

15. The I/O module of claim **14** wherein the electrical switch provides a switchable connection to a first electrical voltage and a resistive connection to a second electrical voltage so that when the switchable connection is open the direction signal indicates that the releasable terminal should operate as a sinking DC output.

16. The I/O module of claim **12** wherein further including a first and second optical isolator receiving at an isolated input the transistor control signals for the first and second transistors and including the step of receiving at an isolated output a first DC voltage for generation of the isolated transistor control signals.

17. The method of claim **12** further including an illuminated indicator associated with the releasable terminal and including the step of illuminating the illuminated indicator when the digital control signal is logically true to provide a visual indication of when the digital control signal is logically true.

18. The method of claim **12** further including the step of communicating the digital control signals using a serial communication circuit exchanging serial data with the industrial controller.

19. The method of claim **12** wherein further including the step of providing the state of the digital control signals using an industrial controller executing a stored program to read signals from input I/O modules connected to the controlled equipment.

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